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CLASSIFICATION OF PHYSICAL GEOGRAPHICAL PROCESSES AND PHENOMENA OF ENGINEERING IMPORTANCE

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/Diagram and tables referred to herein are appended./

I

Physical geographical processes and phenomena of interest to the engineer, which arise with the interference of man in natural conditions, have received the designation "engineering-geological" (G. N. Kamenskiy); these and natural physical geographical processes are extremely diversified. Kamenskiy (1936) gives a very incomplete list of them. In his opinion, they comprise the following:

(1) Sinking and deformation of rocks under the effect of the weight of structures. (2) Sags of loess-like rocks under influence of moistening and stress. (3) Landslide phenomena. (4) Deformation under influence of the leaching and washing out of mineral particles from rock strata; karst phenomena; suffossion; and filtration deformations. (5) Phenomena of quicksands. (6) Deformation under the influence of congealment, chasms. (7) Deformation of rock masses under the influence of mountain pressure. (8) Processes of silting of reservoirs. (9) Erosion of banks of reservoirs, and processes of formation of banks under the effect of new conditions brought about by structures with the aid of water.

A certain systematization of these processes and phenomena may be found in the work of Academician F. P. Savarenskiy (1937). All physical geographical phenomena having engineering importance are broken down by him into the following categories:

A. Phenomena connected with the action of surface waters (oceans, lakes, rivers, canals)

1. The washing away of banks and their collapse (marine and fluvial abrasion)

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2. Erosion of slopes (ravines)

3. Flood waters which erode land on denuded hills (moors)

B. Phenomena connected with the action of surface and underground waters

4. Swamps

5. Sags

6. Karst phenomena

C. Phenomena connected with the action of underground and surface waters on slopes.

7. Landslides

D. Phenomena connected with the action of underground waters

8. Suffossion

9. Quicksands

E. Phenomena connected with the action of wind

10. Scattering and drifting

F. Phenomena connected with the freezing and thawing of ground

11. Freezing of soil

12. Permafrost and its manifestations

G. Phenomena connected with internal forces in rocks

13. Sinking, compression, and swelling

H. Phenomena connected with internal forces of the earth

14. Seismic phenomena

I. Phenomena connected with the activity of man

15. Surface and underground deformations due to deep artificial underground workings.

The proposed classification is the first and only attempt at a definite systematization of phenomena having engineering importance. In this lies the great service of Savarenskiy. At the present time, however, it cannot satisfy us. First of all, it must be noted that it is incomplete. The given scheme does not reflect all physical geographical phenomena, and the list of processes which have importance for the engineer is not complete.

In addition, the division of physical geological phenomena into categories is not precise. Actually, the category of "surface waters" includes the activity of flowing waters, of pluvial waters, and of standing waters, whose mechanism, results, and phenomena caused are very different, as well as the place of their manifestation (climatic zones).

It is hardly possible to distinguish the action of surface and underground waters on slopes, with which Savarenskiy connects landslides. Surface waters on a slope where landslides appear may either act in the form of a common washout or appear as erosional action. For the most part, however, the

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influence of surface waters on landslides will be evident in the undercutting of a slope, the saturation of rocks with water, etc.

Lack of precision in the definition of physical geographical phenomena is also evident in his "phenomena connected with the freezing and thawing of ground."

The subheadings in Savarenskiy's above-mentioned outline provoke a number of doubts and questions, for example, the phenomena of quicksands, permafrost, and others.

Thus, the scheme under consideration requires supplementation and correction. The principle on which it is based--the classification of physical geographical phenomena according to the kind of process--seems to us absolutely correct. By dissecting this scheme and supplementing it, it is possible to obtain a classification on a correct genetic foundation.

All the enumerated obscurities and a certain lack of precision of the given grouping of phenomena, it seems to us, arise as a result of a general lack of development of the problem of the classification of physical geographical processes. Therefore, we must first examine the problem of the definition of physical geographical processes, and acquaint ourselves with their existing classifications.

It must be said immediately that in our country the situation in regard to this problem is far from favorable. A special article by the author, in which a genetic classification of exogenous physical geographical processes is proposed, is devoted to a consideration of these problems. However, for building up a classification of physical geographical processes which have engineering importance, it is necessary to take into consideration not only exogenous phenomena but also endogenous processes, and the category of processes which we have designated "endolithogenous"; in a number of cases the latter have a tremendous engineering importance. They include such processes as are connected with the rocks themselves, and with the internal forces in them (molecular energy). These processes are frequently determined by changes in the physical and physicochemical composition of rocks and their character, frequently under the diverse action of ground and surface waters. These processes were originally distinguished by Savarenskiy, and they may be found in his classification. However, they are understood by him in a considerably narrower sense. We connect with these processes the phenomena of sinking, swelling, shrinkages, sags, quicksands, and others, which owe their appearance to the internal properties of the rocks themselves. They are all connected with definite conditions of appearance and involve changes in the morphology and structure of the rock itself.

As it is well known, any rock is characterized by a definite complex of thermodynamic and physicochemical conditions of formation and existence. We consider that endolithogenous processes are connected with phenomena occurring under normal thermodynamic conditions. This sharply distinguishes them from those which occur in rocks under conditions of high temperatures and pressures. The rock is in equilibrium with the surrounding medium--in its field of stability (Fersman). But with the modification of these conditions the mobile equilibrium is upset, and the rock begins to change in search of a new equilibrium.

Changes of the system: The rock plus the surrounding medium tends to seek a condition with the least reserves of free energy (Fersman). Endolithogenous processes occur especially energetically in the surface portions of the lithosphere in a zone of weathering, which represents the cortex of weathering where the processes of chemical and mechanical destruction of the rocks reach a maximum development. Under these conditions finely dispersed rocks, characterized by their ability to change their physical composition depending on the surrounding medium are formed. Electrical charges are formed on the surface of a division of

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two phases of these rocks; this may also influence the course of the processes within the rocks (Priklonskiy, 1943).

All the phenomena enumerated above, which we connect with endolithogenous processes, are not developed under the influence of molecular energy in pure form alone. Inasmuch as they appear in the surface portions of the lithosphere, the influence of another form of energy is also evident on their operation--that of the sun, which determines a diverse complex of various physical and physicochemical phenomena and processes.

In addition, it may be said that the exogenous processes themselves are accompanied to a considerable degree by parallel endolithogenous processes. In a number of cases, it may be considered that the latter are even the cause of the development of certain exogenous physical geographical phenomena, for example, certain varieties of landslides, etc.

The isolation of a new category of endolithogenous processes, which we separate from exogenous and endogenous, must, it seems to us, contribute to a more precise understanding of the nature of various physical geographical phenomena. These three categories of processes also define all those phenomena which are important from a practical standpoint.

Summarizing the above, we may depict the correlations of these processes in Diagram 1, showing categories of physical geographical processes and the forms of energy which determine them.

An attempt at isolating the indicated categories of processes was also made by Savarenskiy, in whose scheme these processes are reflected (see outline above). Of the endogenous phenomena, however, he took account only of the seismic ones; and in regard to the phenomena connected with the internal forces of the rock, he limited himself to an examination of sinking, compression, and swelling. It is not difficult to show that a number of other phenomena connected with these categories of processes also have great engineering importance. In this respect our classification is a further development of the one proposed by Savarenskiy.

Another principle may be noted which, it seems to us, must be kept in mind when building up a classification: a calculation of zonality in the manifestation of a number of processes.

Actually, the connection between the processes of denudation and climate may be easily illustrated by Diagram 2. Examining it, one may see that each of the processes had its maximum of development only under absolutely definite climatic conditions. For example, glacial phenomena are clearly manifested only under conditions of a nival climate; the action of the wind is manifested in an arid climate, etc.

In the manifestation of processes, however, factors other than climate also play a role, such as vegetation. The latter influences the intensity of the processes connected with the action of flowing waters: erosion. Zonality is also clearly manifested in the processes of weathering (K. D. Glinka, 1931). In addition to latitudinal zonality, the same processes are also subject to vertical zonality, which may be clearly seen from Diagram 2.

Among the processes being considered, it seems possible to distinguish those which are not subject to the law of zonality and from this standpoint they are intrazonal and azonal.

Examining the distribution of various groups of processes from this standpoint, it is possible to establish a definite regularity. Among exogenous processes the following will belong to the zonal ones: those connected with the activity of processes of weathering, of ice, of wind, of pluvial and melted-snow waters, and of flowing waters.

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Azonal exogenous processes are represented by gravitational ones, which must manifest themselves most energetically in strongly dissected localities and mountainous regions; and by processes connected with the activity of wind, man, and standing and underground waters.

All endogenous processes are subject to rules and zonality of a completely different order, connected with the peculiarities of composition and structure of the crust, and primarily with the distribution of such of its elements as platform and folded zones, regions of piedmont depressions, and others. From the standpoint of climatic zonality they all will belong to the group of azonal processes.

The last group--that of endolithogenous processes--has as yet been studied very little. The development or zonality in their appearance (zonality connected with climatic factors) is a matter of the future. However, it is already clear to us now that phenomena may be distinguished among them, both subject to zonality and azonality.

Such is the general outline of our classification of various physical geographical processes having engineering importance. Expressing it in detail, we may distinguish a number of phenomena and processes with which both the engineer and the practical builder must reckon.

The following zonal exogenous processes belong to such phenomena:

1. Those connected with processes of weathering: (a) eluvial formation, and (b) freezing and thawing.

2. Those connected with the activity of ice which forms with seasonal fluctuations of temperature (from surface and underground waters): (a) chasms, (b) layers of ice and ice-covered hills, and (c) fluvial ice (surface and bottom).

3. Those connected with the activity of wind: (a) the phenomenon of scattering and drifting, and (b) snowdrifts.

4. Those connected with the activity of pluvial and melted-snow waters: (a) washout (erosion of soils), and (b) solifluction.

5. Those connected with the activity of flowing waters: (a) scouring, (b) the formation of ravines and the erosion of slopes, and (c) flood waters which erode land on denuded hills.

6. Those connected with the activity of standing waters: swamps and lakes.

Intrazonal and azonal exogenous processes of interest to the engineer include:

1. Phenomena connected with the manifestation of gravitational processes: (a) cave-ins and rock debris, (b) avalanches, and (c) landslides.

2. Phenomena of drifting and scattering, caused by the action of the wind.

3. Various artificial effects and deformation due to the activity of man.

4. Phenomena connected with the action of standing waters: (a) scouring (abrasion), (b) inundation, subsurface inundation, and swamping, and (c) silting of reservoirs.

5. Finally, phenomena connected with the activity of underground waters: (a) suffossion and filtration deformation, (b) karst or chemical suffossion, and (c) swamping.

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Endogenous processes, which belong entirely to the group of intrazonal and azonal, include two varieties of phenomena.

One is connected with tectonic processes, to which belong: (a) phenomena of epeirogenesis, and (b) mountain pressure. Both phenomena are connected with tensions in the crust produced by static and kinetic forces determined by the weight of rock and by tectonic tensions.

The second variety of phenomena is connected with the physics of the earth, and belongs to the group of geophysical phenomena. To this we must refer: (a) seismic phenomena, and (b) phenomena of geothermics.

Finally, the last group of endolithogenous processes includes both zonal and azonal processes.

The first category includes: (a) foliation and exfoliation of rocks, and (b) sags in loess-like rocks. The appearance of both these phenomena is subject to climatic zonality.

The second category of endolithogenous processes, in which zonality of appearance could not be discovered, represents a rather wide group of phenomena which are not exhausted by the adduced list.

To them belong: (a) quicksands, (b) sinking of rocks and their deformation, (c) swelling of rocks due to unloading, (d) fracturing of rocks (from exogenous factors), (e) sags in lavas, (f) shrinkage, and others.

If by the above enumeration we establish laws for the appearance of various categories of processes by area, then it is also necessary to note another law. It consists of the definite conjunction of these processes, their interpretations, and their interdependency. Under natural conditions they are extremely complicated, and as yet they have by no means been completely explained.

Such is the idea of a classification of various physical geographical processes having practical importance. (Russian editor's note: Classification table is not printed for technical reasons.)

In presenting it, we were guided first of all by the desire to bring into a certain clarity and system all those manifold phenomena which the engineer-geologist and the geomorphologist must encounter in practical work; a system which would facilitate the understanding of the laws of the extension and interrelations of the various processes, and would give initial directions in the ways and methods of study of all these phenomena. One cannot help noting our indebtedness to A. Ye. Fersman in our examination of the above questions. "In our age of the accumulation of a tremendous amount of descriptive, observational, experimental, and analytical material, it is impossible to work without a generalizing working hypothesis..." (1940).

The attempt to devise a system for physical geographical phenomena having engineering importance, and to take note of the general rules of their manifestation and interrelations, is surely not free of defects; it represents such a working hypothesis. It is hoped that this hypothesis will be widely used in dividing "engineering geology" and "applied geomorphology" into their proper subdivisions.

II

Examining the given classification of physical geographical processes having engineering importance, we must arrive at a number of general conclusions.

The rather detailed enumeration of physical geographical processes which we have given shows, first of all, that the investigator occupied with this problem must be thoroughly acquainted with the problems of dynamic geology and geomorphology, and must be able to give a definition for the various processes. One may subscribe completely to the words of Savarenskiy (1944), that "dynamic geology is the foundation on which engineering geology is built." In all probability, in engineering geology, problems to which little or no attention was paid previously must be considered. Such problems include phenomena of avalanches, fluvial ice, snowdrifts, phenomena of drifting and scattering, erosion of slopes, silting of reservoirs, phenomena of geothermics, epeirogenic movements of the crust, phenomena of foliation and exfoliation, phenomena of fracturing of rocks, sags in lavas, phenomena of shrinkage, and a few others.

The irregular distribution in space and the diverse conjunction of the physical geographical processes enumerated in Table 1 cause one to consider engineering-geological problems in a geographical and regional cross section, with a consideration of climatic and geotectonic zonality. Such an approach permits one to reach a more correct evaluation of phenomena having engineering importance; to concentrate one's attention on those processes which are of prime importance for a given climatic and orographical zone; and correctly to choc and apply methods of work and investigations.

The examination of the processes and their interrelations, in particular, the role of the activity of man in their manifestation, again raises the problem of the correctness and necessity of the isolation of engineering-geological processes, and the definition of the problems of engineering geology as a science as noted by G. N. Kamenskiy (1936).

Examining Table 1, one may see that a majority of the processes interact with one another, and are manifested in complicated combinations and interconnections.

The technical activity of man, which causes the disruption of natural conditions, influences the course of the majority of natural processes to a greater or lesser degree. Indeed, it would be difficult to name an engineering process which would not have analogies among natural processes. Thus, the influence of man consists of the modification of the natural conditions of a locality, and the modification of the conditions of appearance of natural processes which are either active or dying.

It seems to us that to lay down a boundary in nature between engineering-geological and natural physical geographical processes is not only difficult but absolutely impossible. We have a complex of factors, which determines the complicated course of the process, and the activity of man results in changing some of them. If the process develops again, the complex of factors determining it has already taken place in nature; but their combination was such that it did not appear in the given place. The establishment of engineering projects changes these correlations, and the process begins to appear. But how is it to be distinguished from a natural phenomenon of the same order? Evidently not qualitatively; the distinctions can only be quantitative. They are the same natural processes.

That is why it seems to us that the term, "engineering-geological processes," must be approached in a critical manner.

Within the quoted list there is a second group of physical geographical processes with whose origin the engineering activity of man is not connected, but which do concern man in so far as the consequences of the above-mentioned phenomena affect man. These are the phenomena which must be taken into consideration in the building and operation of structures because their manifestation may be harmfully reflected on the structures, but which are not produced themselves by the construction. To these belong snowdrifts, avalanches, flood waters which erode land or denuded hills, seismic phenomena, and others. They likewise must all be studied by the engineering-geologist.

A great role in the study of physical geographical processes is assigned to the geomorphologist. More than once, I have had occasion to emphasize that in some of their works the engineering-geologist and the geomorphologist are pursuing the same problems (the study of processes, the demonstration of the dependence between the separate elements determining them, etc.). They use on the one hand, completely different, and on the other hand, rather similar methods of work (N. I. Nikolayev, 1936, 1937).

Unfortunately, however, a great gulf must be noted even now between the works of the engineering-geologist and the geomorphologist. Both parties are, without license, negligent in using the results of the observations, experiments, etc., which each produces. And now it is appropriate to recall and repeat what was said more than 10 years ago:

"Further work of the geomorphologist and the engineering-geologist must proceed in close contact. The former will aid in formulating the problem more broadly, will connect the phenomenon being studied with a number of general problems, and will obtain for their solution such facts, methods, etc., which are unknown to the latter.

"The engineering-geologist usually shuns theory. He formulates a problem definitely and precisely in connection with those practical purposes which face him; but in a majority of cases he solves them unilaterally and narrowly. In solving the formulated problems, however, he frequently uses methods which are completely unknown to the geomorphologist, or in which the latter is little versed.

"The most effective treatment of the problem concerning the study of the processes and their influence on projected construction seems possible to me only through the close cooperative efforts of specialists in these two disciplines, which at first glance have nothing in common."

Applied, and engineering geomorphology must be the connecting link between engineering geology and geomorphology (Ye. P. Konovalov, 1941; P. N. Panyukov, 1937).

The problems may be summarized as follows:

1. The study of the conditions under which physical geographical processes appear and the separate factors determining them; the application of a quantitative evaluation using physical dimensions (gram, centimeter, second), thereby revealing the relative importance of the separate factors determining the process.

2. The study of the physical geographical processes which appear at a given time in the region being studied, and their historical development.

3. The forecast of the physical geographical phenomena which may exert an influence on the construction of an engineering project or on its use.

4. An examination of engineering-geological processes in a geographical cross section with a clarification of the role of regional factors in their manifestation.

The solution of the given problems requires a knowledge not only of special geomorphological and geographical methods, but also of the specific methods of historical geology and engineering geology. The geomorphologist must be versed in these methods.

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He will profit particularly from experiments, which will permit him to proceed from a qualitative description of physical geographical processes to a quantitative evaluation of them.

The necessity for taking into consideration all the diversity of physical geographical processes, however, is not equal for all forms of construction. Each form of construction--for example, the building of roads, dams, reservoirs, canals, bridges, etc.--requires the consideration of an absolutely definite complex of physical geographical processes which may be connected with it either as a cause or as a result, and which may interact in some way or other with the engineering project.

In Table 1 (appended) an enumeration of physical geographical phenomena having engineering importance, in accordance with the classification of natural processes which we proposed earlier is given. They are distributed according to type of construction (industrial and civic, roads, dams and reservoirs, canals, ports, bridges, tunnels and subways, military-engineering, and agricultural improvement).

It is not difficult to see that this complex of processes which must be taken into consideration is sharply diversified. Table 2 (appended) makes it possible to evaluate actually, although relatively, the necessity of considering physical geographical processes in the surveying and construction of buildings. In it we have tried to show the quantity of the various phenomena connected with various groups of processes which must be heeded; they are expressed quantitatively and in percentages.

The quantity of various phenomena must decrease even more if we take into consideration zonality in the manifestation of these processes. Knowing the climatic zone where one or another form of construction is located, it is possible to foresee quite precisely the complex of phenomena which may be encountered by the geologist; and starting from this, to plan a method of work and investigation of them.

Thus, a geographical approach is necessary for the solution of the various engineering-geological problems.

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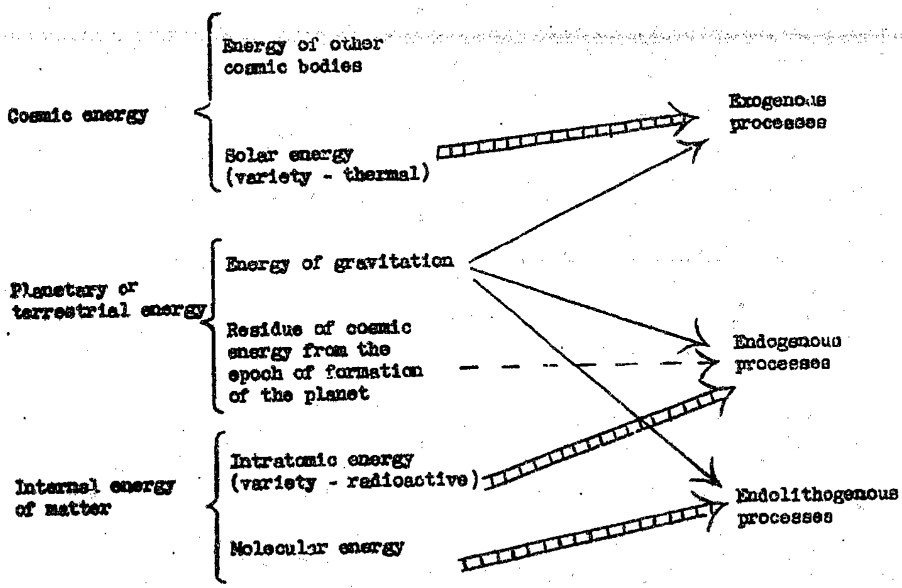
Diagram 1



Legend

Basic form of energy determining the process

Secondary form of energy

Source of energy subject to doubt at the present time

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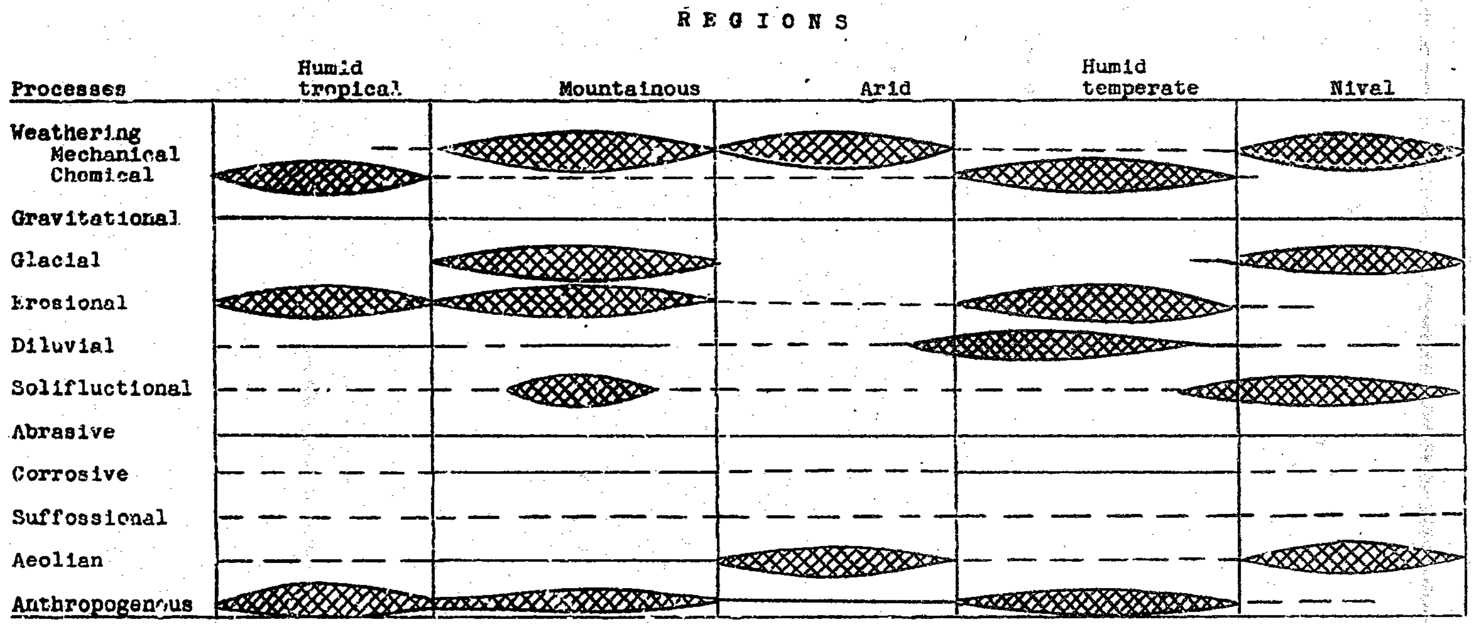

Diagram 2. Distribution of Processes According to Climatic Zones

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Processes: Type of Process	Processes: Effective Factor	Physical Geographical Phenomena of Engineering Geographical Importance	Industrial and Civic Construction	Road Construction	Dams and Reservoirs	Canals	Ports	Bridges	Tunnels and subways	Military-Engineering Constructions; Fortifications	Agricultural improvements
Exogenous – Subaerial	Activity of Process of Weathering	1. Eluvial formation	+	+	+	+	+	+	+	+	+
		2. Freezing and thawing	+	+	+			+		+	+
	Activity of the Force of Gravity	1. Cave-ins and rock debris	+	+	+	+		+		+	
		2. Avalanches	+	+		+		+		+	+
		3. Landslides	+	+	+	+	+	+		+	+
	Action of Ice Forming With Seasonal Fluctuations in Temperature (From Surface and Ground Waters)	1. Chasms		+	+					+	
		2. Layers of ice and ice-covered hills	+	+				+	+	+	
		3. Fluvial ice	+	+	+			+		+	
	Action of the Wind	1. Drifting and Scattering		+						+	+
		2. Snowdrifts (Detention of snow)		+		+				+	+
	Activity of Man	1. Artificial deformations	+	+					+	+	
Exogenous – Subaqueous	Action of Flowing Waters	1. Scouring	+	+	+	+		+		+	
		2. Formation of ravines, erosion of slopes	+	+							
		3. Flood Waters eroding land on denuded hills (moors)	+	+	+	+		+		+	+
	Action of Standing Waters	1. Scouring	+	+	+		+			+	
		2. Inundation and subundation	+	+	+					+	+
		3. Silting of reservoirs			+					+	

Table 1

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Table 1 (Contd)

Processes: Type of Process	Processes: Effective Factor	Physical Geographical Phenomena of Engineering-Geological Importance	Industrial and Civic Construction	Road Construction	Dams and Reservoirs	Canals	Ports	Bridges	Tunnels and subways	Military-Engineering Constr Fortifications	Agricultural Improvements
[illegible] Subterranean	Action of Underground Waters	1. Suffosion	+	+	+	+		+	+	+	
		and filtra-								+	+
		tion defor-mations		+	+	+					
		2. Swamping									
		3. Karst	+	+	+	+	+	+	+	+	
Endogenous Tectonic processes	Slow movements of crust, producing tensions, static loading, and decomposition of radioactive elements	1. Seismic	+	+	+	+	+	+		+	
		2. Geothermics		+	+	+			+		
		3. Epeirogenesis									
		4. Mountain pressure					+		+		+
									+	+	
Endolithogenous	Process of modification of physical and physico-chemical composition of rocks, connected with internal forces in rocks and their character under effect of ground and surface waters	1. Quicksands	+	+	+	+	+	+	+	+	
		2. Foliation and exfoliation			+	+					
		3. Sags in loess-like rocks under moistening and stress	+	+		+		+		+	+
		4. Sinking of rocks and their deformation under the effect of loading	+	+	+		+	+		+	
		5. Swelling from			+			+			
		unloading			+		+	+			
		6. Fracturing									
		7. Sags in lavas	+	+							
		8. Shrinkage	+	+	+	+				+	

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Types of Construction	Exogenous Phenomena			Endogenous	Endo-lithogenous	Total	
	Sub-aerial	Sub-aqueous	Sub-terranean			Quantity	Percentage
Industrial and Civic	7	5	2	1	5	20	62
Road	12	5	3	2	5	26	80
Dams and Reservoirs	5	5	3	2	6	21	65
Canals	34	2	3	2	4	15	45
Ports	1	1	1	2	3	8	24
Bridges	6	2	2	1	5	16	49
Tunnels and Subways	2	-	2	3	2	9	27
Military-Engineering	12	5	3	2	5	27	85
Agricultural Improvement	7	3	1	1	3	14	41

Table 2

- END -